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ADMINISTRATIVE INFORMATION

The work documented in this report was sponsored by the Defense Advanced Research Projects Agency (DARPA). The work was a joint effort by Harry A. Schenck of the Naval Command, Control and Ocean Surveillance Center, RDT&E Division and Janine L. Fales of Los Alamos National Laboratory.

Released by
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BACKGROUND

As part of the Submarine Technology Program, the Defense Advanced Research Projects Agency (DARPA) recently sponsored a Low-Frequency Structural Acoustics Benchmark Exercise. The purpose of this exercise was to test and validate several major computational codes that have been developed to solve acoustic scattering problems of elastic objects in a fluid. All of the computations of scattering were done on a Cray YMP at the Los Alamos National Laboratory (LANL). The result of each problem was a large digital data set, which was analyzed and displayed off-line on a workstation using specially developed visualization techniques. The Benchmark Exercise began in May 1991, and a comprehensive report on the results will be issued separately by LANL.

The purpose of this report is to describe some of the visualization techniques and procedures that were developed to review, compare, and analyze the large amount of computational data generated in the Benchmark Exercise. It was felt that the visualization approach and techniques should be described in an independent document because the techniques are generally useful in representing scattering or target strength functions generated by any means, and the approach is applicable to any computational or experimental problem in which there is a need to understand large multidimensional data sets.

THE NEED FOR VISUALIZATION

In the Benchmark Exercise, a series of nine problems was developed to test the accuracy and computational efficiency of six different structural acoustics codes. In each of the problems, the forcing function was a steady-state plane wave at a set of densely spaced frequencies incident upon the scatterer from one of several different directions. In all the problems, it was required that the code generate the complex numbers representing the complete three-dimensional far-field scattering function. In some of the problems, it was also required that the code generate the complex surface pressure and normal velocity on a dense grid over the complete surface of the scatterer. The problems and results were specified in nondimensional terms.

A far-field data set typically consisted of all the information needed to reconstruct the normalized target strength or complex scattering function at a set of frequencies over all space. Each set was given a name associated with the problem and the code that generated it, and an extension of `.ff#`, where the # was a single digit identifying the incidence angle. Each set was a file containing a three-dimensional array of complex coefficients in a circumferential harmonic decomposition of the three-dimensional field, as follows:

$$p(\varphi) = \sum_{n=0}^{N-1} a_n cos(n\varphi) + \sum_{n=0}^{N-1} b_n sin(n\varphi),$$

where N is the number of harmonics and $b_0 = 0$ .The dimensions of the array are the number of frequencies, the number of azimuthal harmonics, and the number of bistatic observation angles. In a typical problem, the computation was made at 331 frequencies, 73 observation angles, and 3 incidence angles, using 7 harmonics. Each complex number required a 16-bit (IEEE) binary representation, so the far-field output from one problem typically comprised three 1.4-megabyte files.

Similarly, a surface pressure (`*.sp#`) or normal velocity (`*.nv#`) data set was also a three-dimensional array of complex numbers, whose dimensions were the number of frequencies by the number of harmonics by the number of grid points describing the generator line of an axially symmetric object. The number of grid points varied with the code, but was typically of order 250 in a large problem, resulting in surface files of approximately 5 megabytes each.

Some of the problems were run more than once for each structural acoustic code, so the total amount of computational data generated and reviewed in the Benchmark Exercise approached 5 gigabytes. Clearly, an efficient and powerful graphical postprocessing method was required.

APPROACH

In addition to the sheer magnitude of the problem, there were many other challenges inherent in trying to display, compare, and understand the results. New formats had to be conceived and implemented to display or compare large amounts of data at one time. The judicious use of color and animation to make the results more understandable was anticipated. In addition to rapid and convenient software development, the need for efficient repetition of tasks for many different data sets was recognized. Reproduction of workstation displays on paper or videotape was also important.

With these criteria in mind, the command language version of PV-WAVE* software was chosen as the means for accomplishing the visualization tasks on available workstations (Sun and Silicon Graphics). The key features of this software that were of importance to the task at hand were as follows:

- Availability of a large number of basic mathematical and graphical operations as simple callable procedures and functions
- Availability of a high-level programming language, with all the usual logical constructs
- Ability to run the software interactively, retaining data and intermediate variables in memory
- Ability to generate new user-defined procedures and functions for efficient development of a family of visualization algorithms
- Ability to develop compiled user-friendly routines for production use by junior programmers
- Speed and efficiency of operation on a workstation, especially with matrix or array operations

The example programs in this document are all written in the PV-WAVE command language, but should be understandable by anyone familiar with a high-level structured programming language.

* PV-WAVE is the trademark for a software product of Precision Visuals, Inc., Boulder, CO.

ARCHITECTURE AND DATA FLOW

An overall guide to the approach used is described in figure 1. At the top of the flowchart are shown the IEEE binary data files written to disk by the structural code that was executing on the Cray YMP. All binary files began with a header in which problem identification and parameter descriptions as used at the time of computation were written. In addition to the far-field, surface pressure, and normal velocity files described above, an additional binary coordinate (`*.bco`) file was written for each problem, containing the set of cylindrical coordinates describing the shape of the scatterer in discretized form. These coordinates were also the locations at which the surface pressure and normal velocities were calculated.

Each shaded rounded rectangle in figure 1 represents one or more PV-WAVE command language routines written to perform a specific function. These routines are small ASCII files having a `.pro` extension, created with any convenient word processor. On the top level of the flowchart, there are three conversion routines (`convffb.pro`, `convbco.pro`, and `convsurb.pro`). These and other `.pro` routines described in this section are listed in their entirety in appendix A. The conversion routines are intended to be used only once on a given data set. The purpose of each conversion routine is to read an IEEE binary file generated by a FORTRAN program on the Cray YMP, and rewrite it as a structured binary file in a format optimized for input to PV-WAVE. One of the built-in functions in the PV-WAVE language is the ASSOC function, whose purpose is to map an array structure onto a named file, thereby permitting the entire file to be read efficiently into memory and to be associated with a structured variable in one statement. Once the structured binary files (`*.fw#` for far-field PV-WAVE files, `*.pw#` for surface pressure, and `*.vw#` for normal velocity) are created, the original IEEE binary files can be discarded or at least archived because they are not needed for subsequent processing of the data.

The `convbco.pro` routine extracts the coordinate information from the `*.bco` file, writes it to a `*.wco` file, and also extracts the header information and writes it to an ASCII `*.hdr` file. This header file is the key to generalizing the remainder of the visualization routines so that a single simple `*.pro` routine will work for any problem, with any choice of modeling variables, independent of the particular structural acoustics code that generated it. The information in the header is made available by calling the procedure `rdhdr.pro` and passing the information as named variables through a common block in `rdhdr.pro` and the routine that calls it. Calling `rdhdr.pro` also causes the header information to be displayed on the screen , as shown in figure 2. The five types of PV-WAVE files on the third level of figure 1 contain all the information present in a solution to one of the benchmark problems.

For the purpose of quickly checking the data set or for developing some new means for visualizing it, there are two workhorse routines called `grabff.pro` and `grabsur.pro`. The purpose of these routines is to quickly read (i.e., "grab") a far-field or surface variable data set and its associated header, and make the information available in high-speed memory for use on the workstation. Each routine also displays a simple representative portion of the data on the screen. In the case of `grabff.pro`, this representation is a set of three two-dimensional color images, as shown in figure 3. One of these (figure 3a) shows target strength in dB encoded in color as a function of polar angle and nondimensional frequency for a fixed azimuthal angle. The other two surfaces (figures 3b and 3c) show the linear magnitude of the scattering function and its phase in the same layout. A color table is included with each figure to show how the tabulated values are translated into a color image. Horizontal cuts of these surfaces represent directivity patterns at some fixed frequency, and vertical cuts represent spectral variations in target strength at some (possibly bistatic) angle. In the case of `grabsur.pro`, two color images are given in figure 4: a "Persian rug" (figure 4a), in which surface pressure or normal velocity is plotted as a function of axial and azimuthal coordinates for a fixed frequency, and a "standing wave" plot (figure 4b), in which the axial variation of the surface quantity is displayed as a function of axial coordinate and frequency for a fixed azimuthal angle. If there are any data format problems, or if a fundamental error has been made in computing the results, this initial visual check is often sufficient to identify the problem. Using the built-in procedures and functions of PV-WAVE, the data in memory can be easily manipulated and presented for visual analysis on the workstation screen in a variety of one-, two-, and three- dimensional formats. This is a fast and convenient way to explore the data. In addition, PV-WAVE provides both a "command history" and a "journaling" feature that make this interactive mode very efficient for the development of new algorithms. Instructions can be issued, recalled and modified, and then saved to form the core of a new `*.pro` routine, because the syntax of the language is virtually identical whether used interactively or read and compiled from a program file.

The rectangle labeled `other.pro` is a generic descriptor on the chart for all the other compiled routines that are described in this document or that were developed during the Benchmark Exercise. A number of such application-oriented routines are listed in the next section, along with a brief statement of the scope or purpose of the routine. Examples of the output are also given as appropriate, although these outputs are not a direct representation of what would be displayed on the screen by the PV-WAVE routine. The complete PV-WAVE code for these routines given in appendix A; however, it is not intended that the code could be used as is, since in many cases it is dependent on the particular data sets available for analysis.

Finally, in reference to figure1, in order to redirect the output of the various routines to a printer or other hardcopy device, two simple routines called `hardcopy.pro` and `closeit.pro` were written. These routines can be used interactively or inserted into compiled visualization code surrounding one or more graphical display statements. They reformat and redirect the output to an encapsulated PostScript file for inclusion in a document or viewgraph using some convenient page-formatting software. For production purposes, some routines were rewritten to make the hardcopy the normal output, or to do both so that the process could be monitored as it was generating the files for producing hardcopy output. Videotapes were also generated using some routines (especially for those cases where animation in time was useful for analysis of the effects of changes in frequency or angle). The simplest way to generate the videotape is to connect appropriate scan converting and recording equipment directly to the workstation.

EXAMPLE APPLICATIONS

Selected examples of visualization and analysis routines are presented in this section. The first two examples are routines used simply to display or visualize far-field and surface results. The next two examples were developed to aid in the comparison of multiple data sets. The last two routines actually process the results in such a way as to reveal the underlying physical mechanisms.

`ff3d.pro` - The purpose of this routine is to fully use the graphic display device to show the three-dimensional character of the far-field scattering function, using both color and distance from the origin to indicate target strength at a given frequency. This gives a more complete geometrical picture of the scattering function than the color images produced by `grabff.pro` which show the variation in polar angle only, for a fixed azimuthal angle. This visualization techinique is particularly useful for understanding whether the results have the correct symmetry in a particular problem. Because each three-dimensional picture is for a fixed frequency, the variation in frequency is shown by animating the display; that is, by showing a sequence of frames at some chosen frequency increment. Figure 5 shows several frames in such an animation.

`plotsur.pro` - The purpose of this routine is to overlay, by means of animation, line plots of either surface pressure or normal velocity as a function of axial node number. This is useful to determine the spatial variation in relation to the surface or internal features of the scattering object, and to observe and understand the difference between pressure and velocity on the surface. Figure 6 indicates the final frame of the animation, which is built up over time by overlaying many different velocity distributions in a selected frequency range.

`envel.pro` - The purposes of this routine are to generate a set of overlays of supposedly equivalent solutions generated by different structural acoustic codes, to allow the user to select a subset of the solutions (possibly having rejected one or more outliers), and then to produce the mean and an envelope that bounds the variations among the data sets. The results of this process are illustrated in figure 7.

`compff_m.pro` - The purpose of this routine is to take two different far-field data sets, display both of them, and then display the difference between them in a similar format. As can be seen in figure 8, the difference plot is rendered using a specially designed color table which highlights the differences; the sign of the difference is retained, thereby providing information about which data set is higher than the other. The routine also allows the user to select or experiment with the dynamic range and with a threshold value below which differences are not considered important and can be blended into the background. This routine calls a secondary procedure named `npff_m.pro`; the PV-WAVE code for this subordinate procedure is not included but is functionally equivalent to `grabff.pro` and is used to read in and display the selected data sets.

`fig8.pro` - The purpose of this routine is to use wave-vector processing to perform spatial transforms of the computed normal velocity in order to reveal the underlying behavior of elastic waves on the surface of the scatterer. It produces the same kind of helical spectra that have been used in holographic work with experimental data to associate the theoretical dispersion curves of free waves on an infinite shell with the actual motion on finite closed bodies. In its present form, it is only appropriate in problems for which there is a cylindrical section of significant length compared to the overall dimensions of the scatterer. The result of this routine is illustrated in figure 9, in which the bright spots indicate waves traveling in one axial direction with a particular helical wave number. Each wave number is an (m,n) pair, where m is the number of axial half-wavelengths along the length of the cylinder and n is the number of the wavelengths that fit around the circumference of the cylinder. The pattern of these spots in the m,n plane has the appearance of a "figure 8," which gives rise to the name of this routine.

`window.pro` - This is a sophisicated use of the PV-WAVE software. The purpose of this routine is to simulate a process that was not carried out in the computational problem, but which controlled the accuracy and resolution of the comparison of computed results with experimental data. Although the computation in the Benchmark Exercise was made for a free-field steady-state situation, the experimental data had been collected in a small tank requiring a short time window to be applied. This routine accepts the computational data in the frequency domain, performs a series of fast Fourier transforms to achieve a real time series with the appropriate sampling, aligns the computed time series, and applies the windows actually used in the experiment. The modified time series is then transformed back to the frequency domain for comparison with the experimental data. PV-WAVE includes the fast Fourier transform and other signal processing functions as built-in procedures/functions. Figure 10 illustrates the end result of using `window.pro`. In the center (figure 10b) are experimental results in the normal far-field format, showing target strength in color as a function of polar angle and frequency. On the right (figure 10c) the computed target strength is displayed without modification, and on the left (figure 10a) the windowed computational results that are the result of simulating the experiment are shown. As a quality check , intermediate time-domain results are displayed on the screen while the routine is running through the data by angle, as shown in figure 11.

SUMMARY

The scattering strength of elastic objects can best be understood by displaying its variations in creative ways. Futhermore, visualization of such large multidimensional data sets provides an efficient means for checking as well as understanding or analyzing such a function. When implemented on modern graphical workstations, the software architecture and routines described here provide a powerful environment for dealing with the results of computer-intensive modeling of this nature. These techniques could easily be modified and employed in the analysis and visualization of computational or experimental data from a wide variety of physical problems.

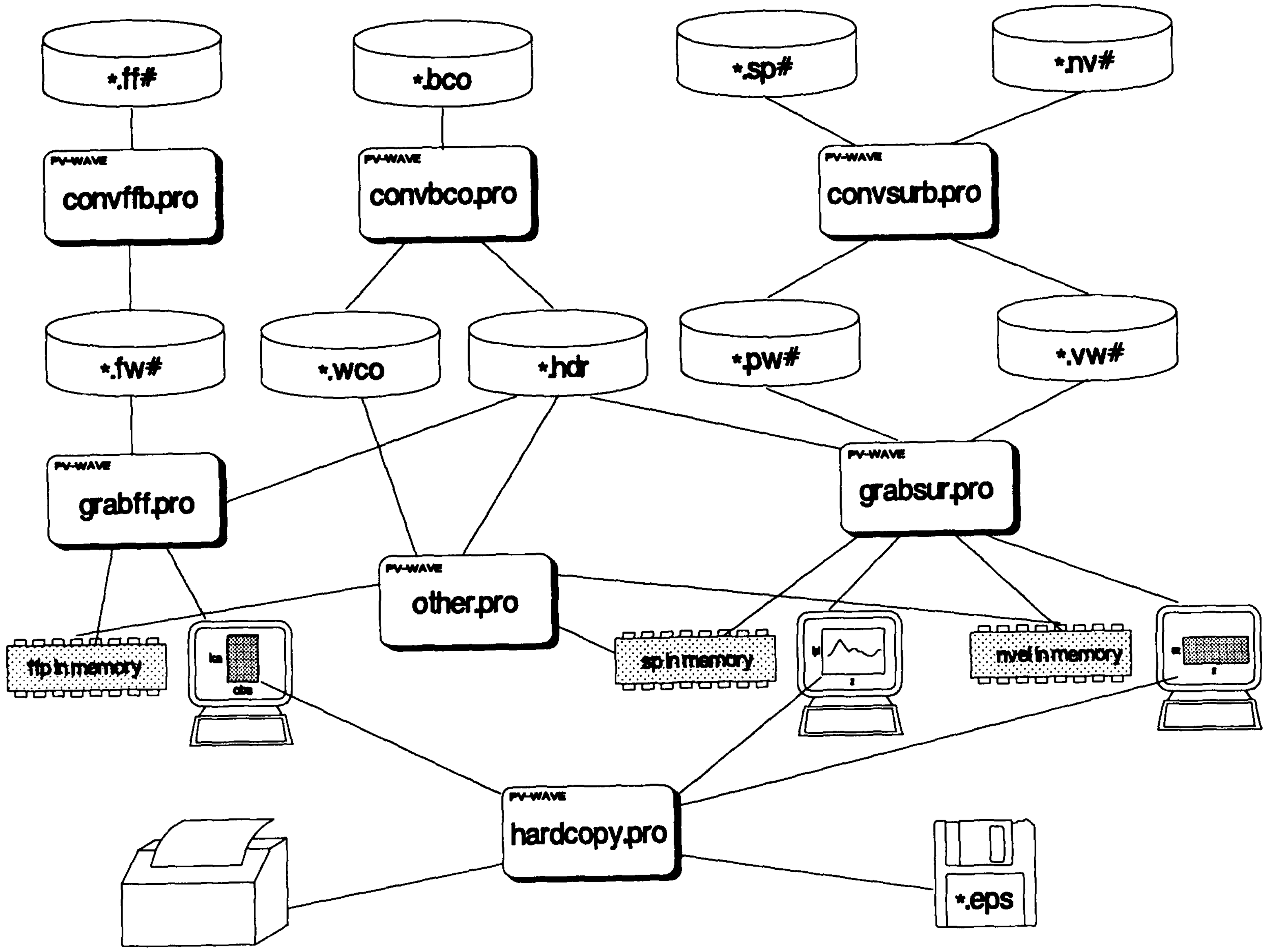


Figure 1. Visualization of Benchmark data sets.

```
Jobname is c1a
Comments: CHIEF with 2% loss
There are 331 ka values from 0.200000 in steps of 0.0100000
The spectral variable is ka
There are   1 ff patterns
              24 areas or rings
              24 coordinate values
               3 theta incident angles
There are   3 theta incidence angles from 0.00000 in steps of  45.0000
73 theta observation angles in ff pattern from 0.0 in steps of 2.50
The fluid density is       1000.00
The sound speed in the fluid is       1500.00
The density of shell is       7850.00
The Youngs modulus of shell is  2.00000e+11
Poissons ratio for the shell is      0.300000
The damping factor is     0.0200000
```

Figure 2. Example output from `rdhdr.pro`.

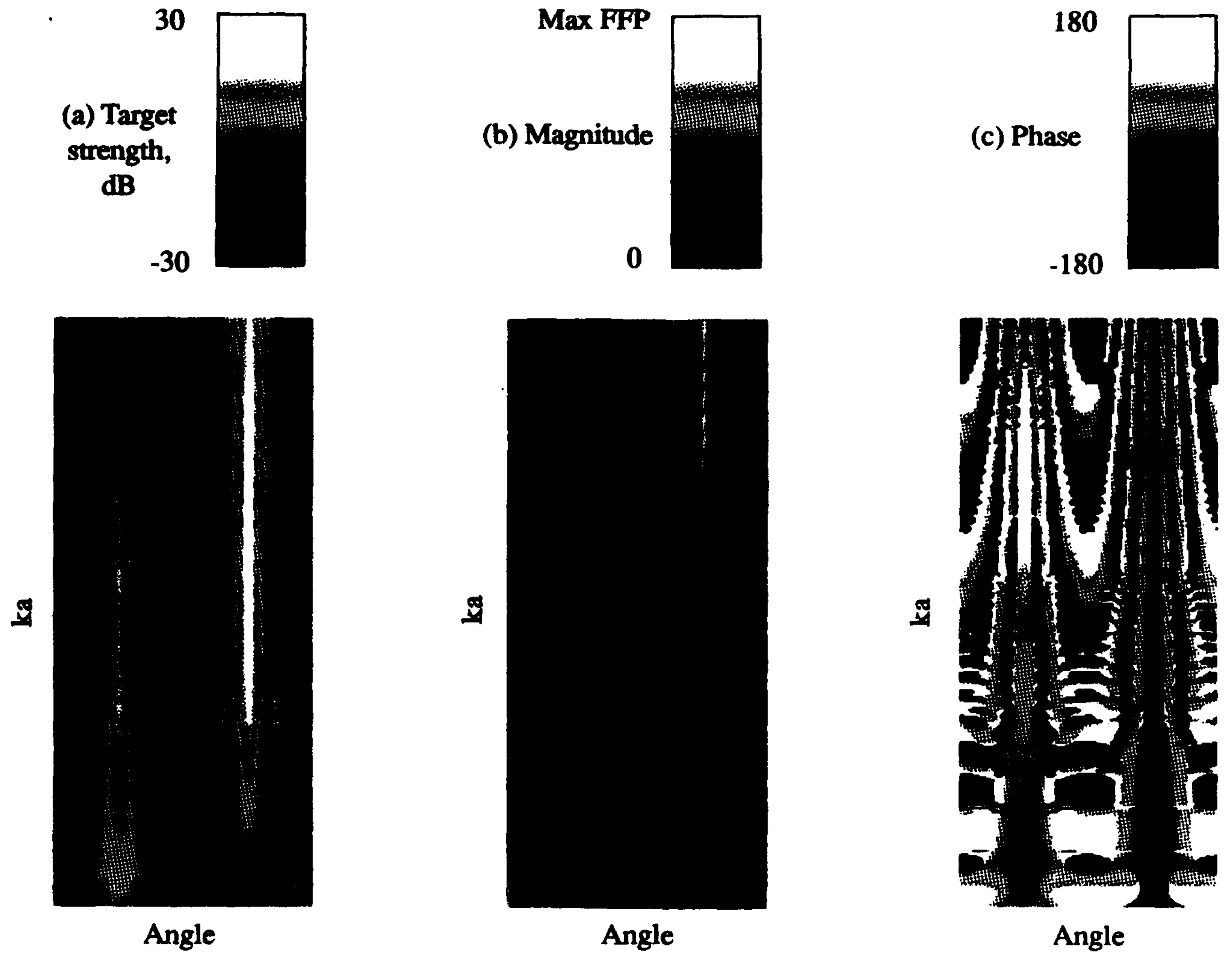
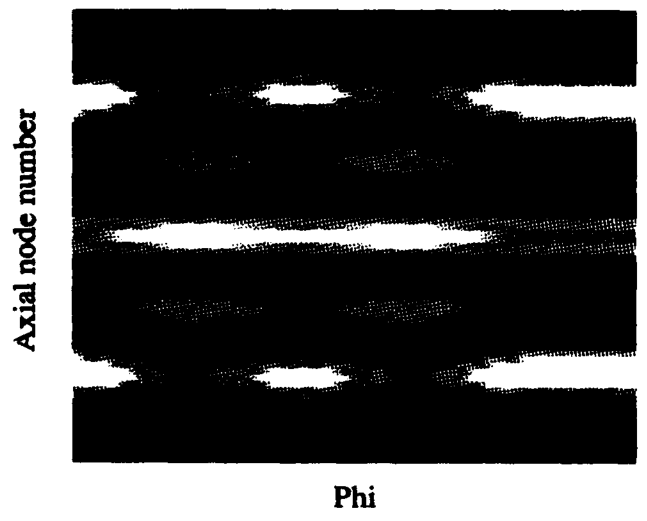
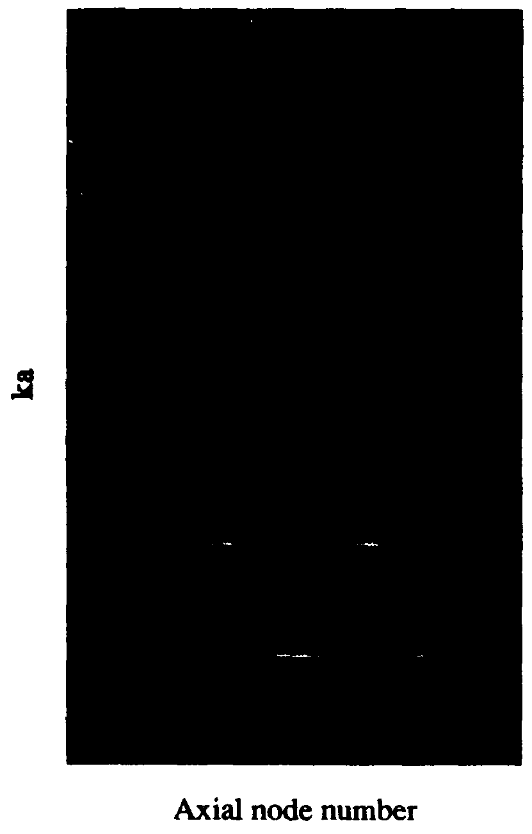


Figure 3. Complex far-field pressure.



(a) "Persian rug," for kabin = 100



(b) "Standing wave" plot, for phibin = 0

Figure 4. Normal velocity, c1b, 90 incidence.

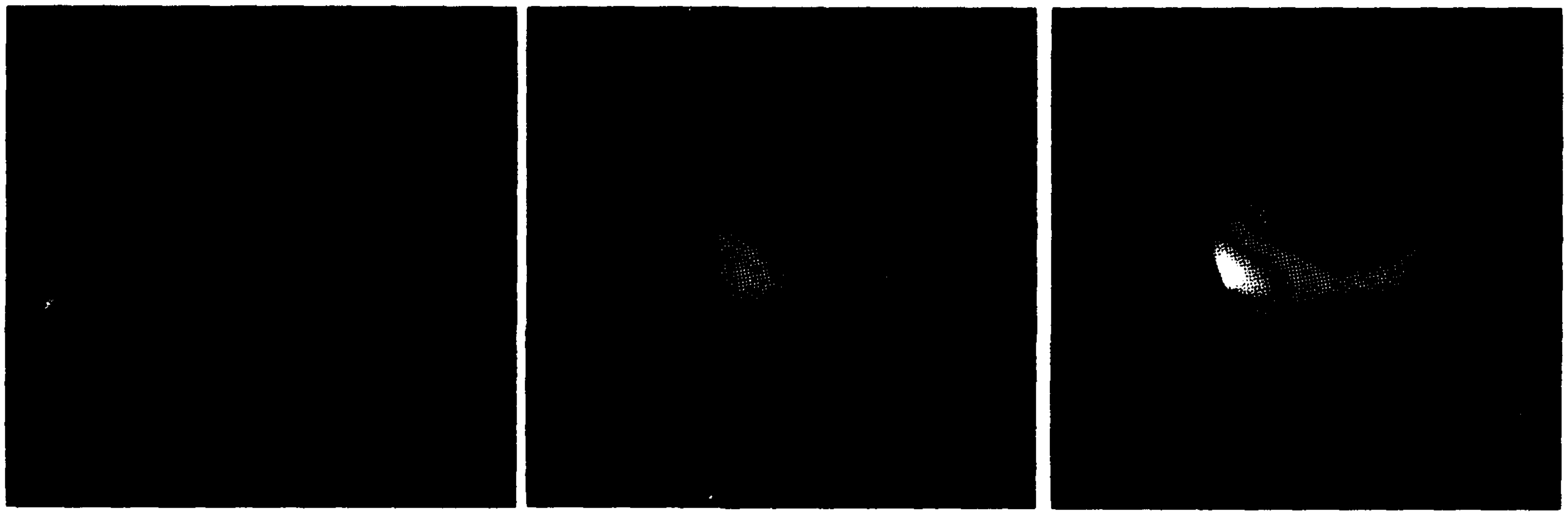


Figure 5. Three-dimensional representation of far-field pressure at several frequencies.

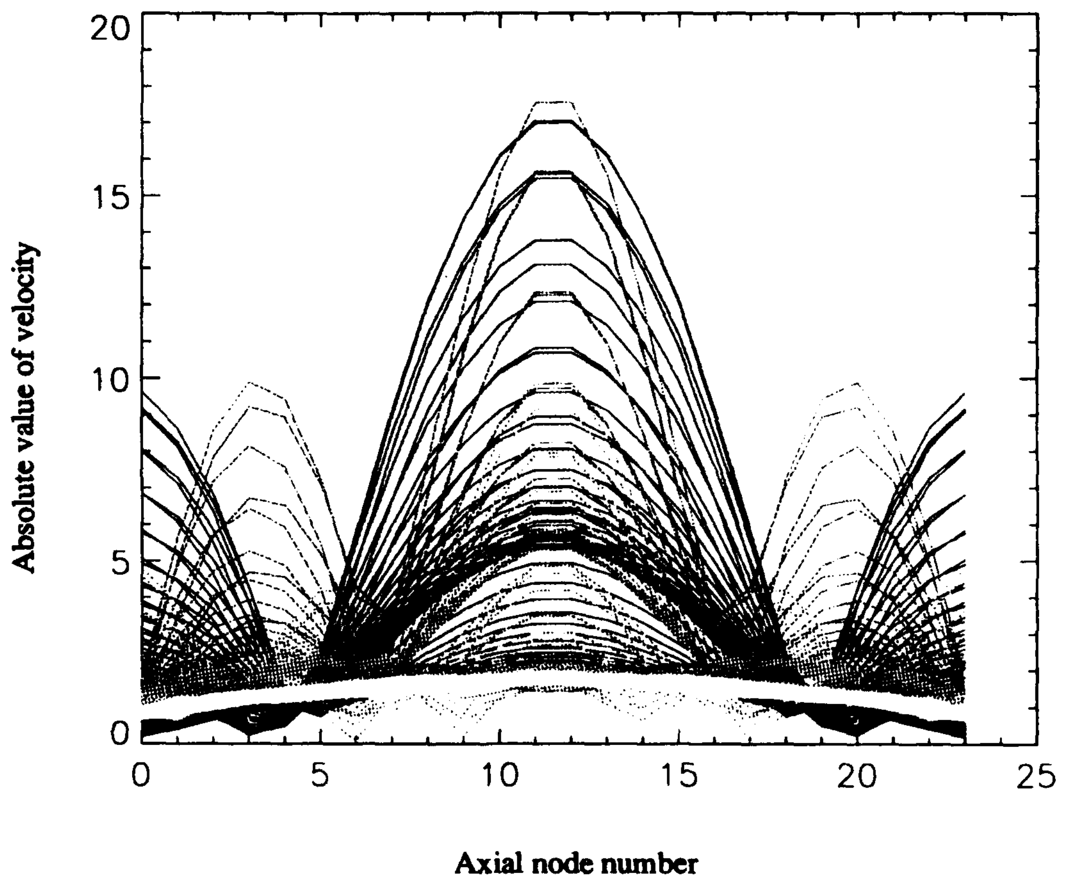
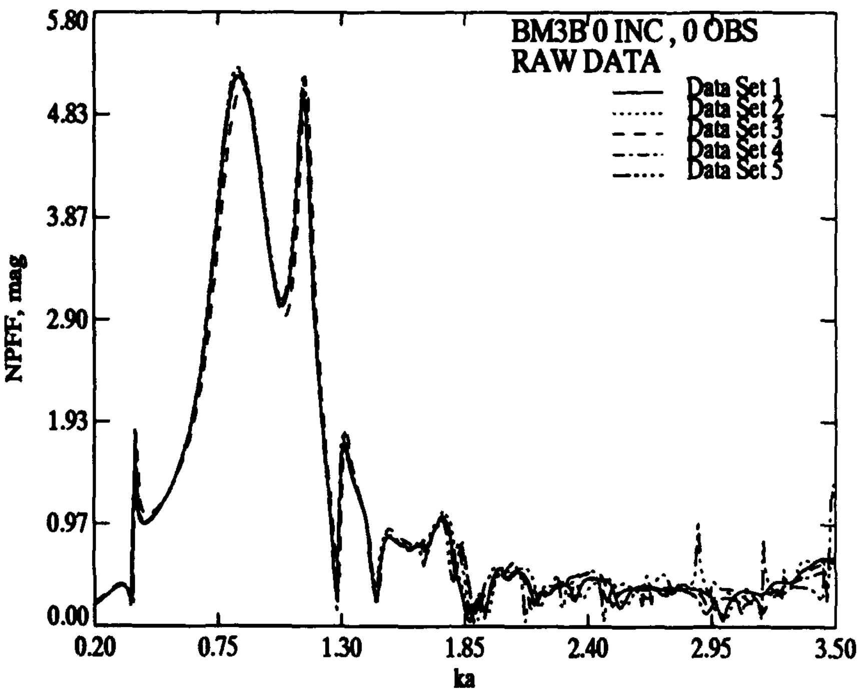
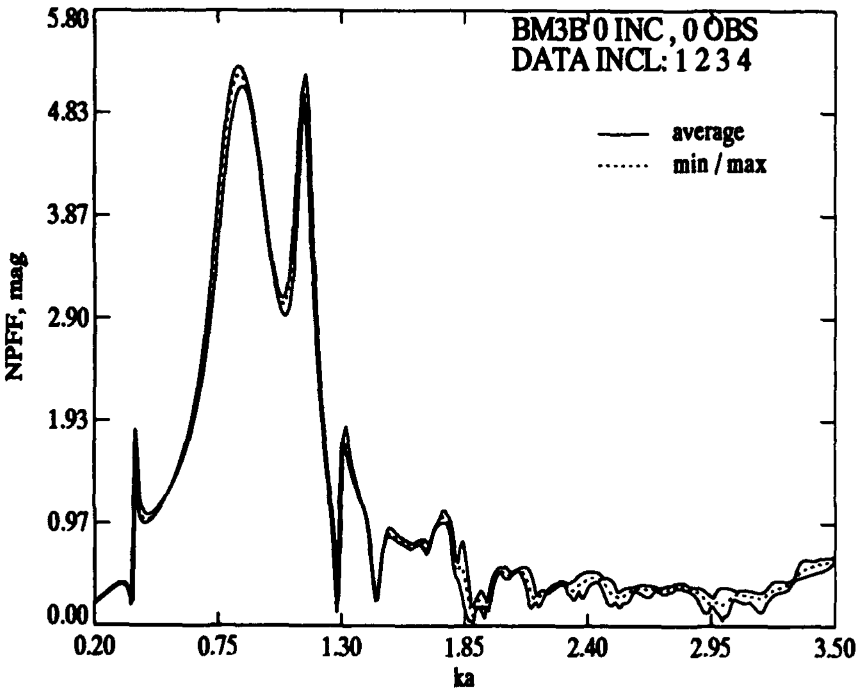


Figure 6. Axial distribution of normal velocity for various frequencies.



(a) Raw data



(b) Envelope of selected data

Figure 7. Data set variation and envelope of selected data sets.

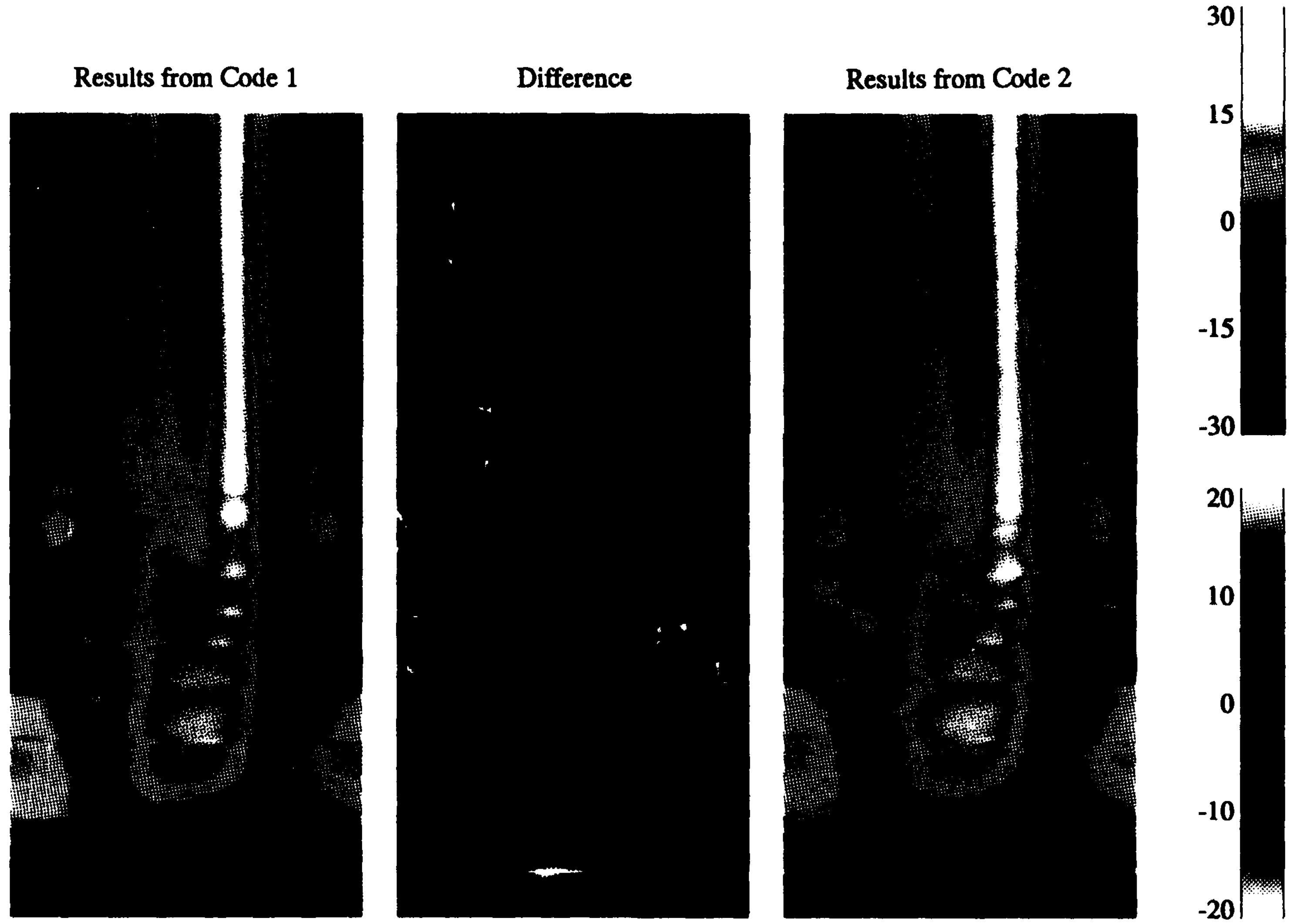


Figure 8. Comparison and differences in target strength.

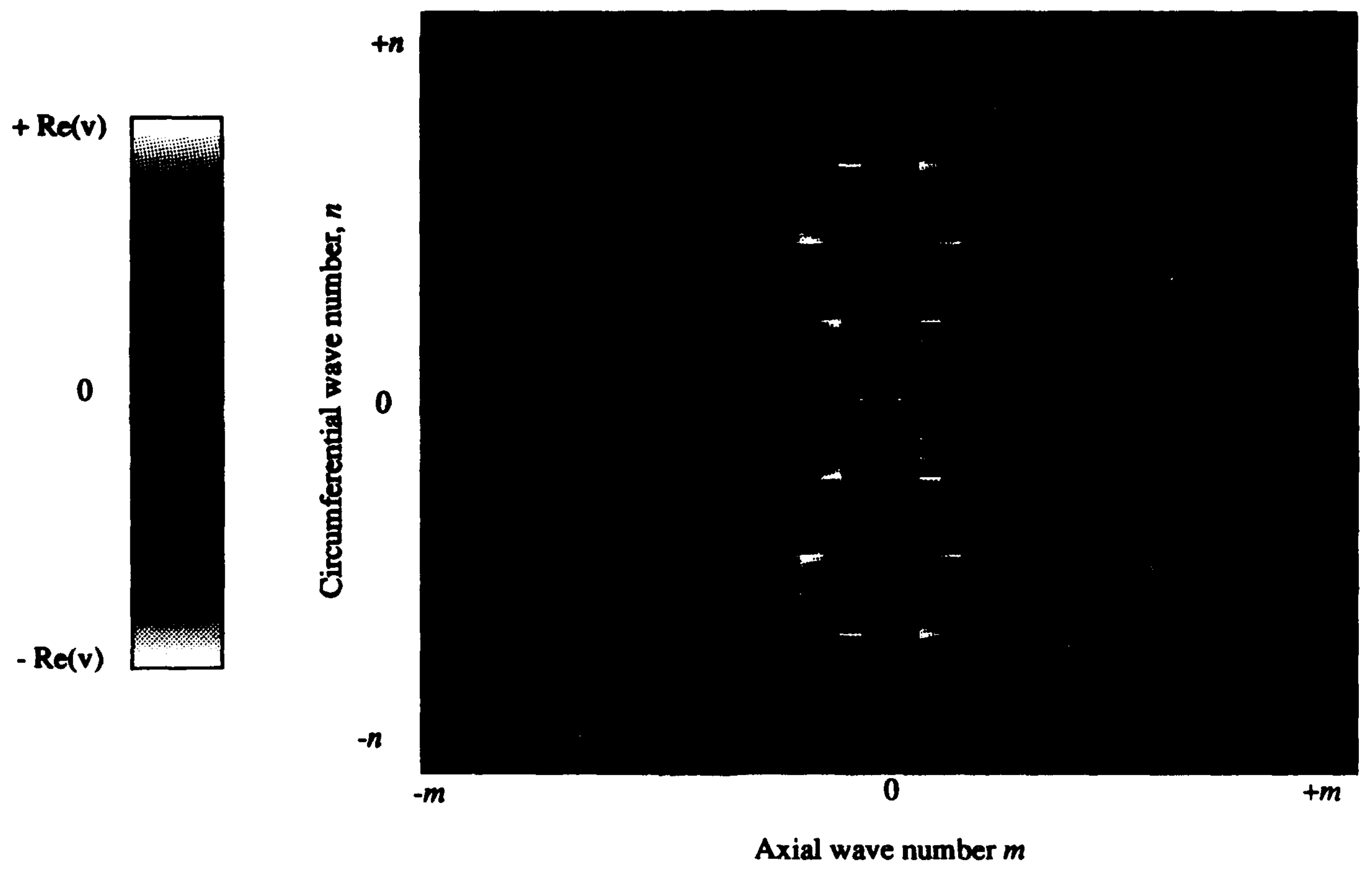
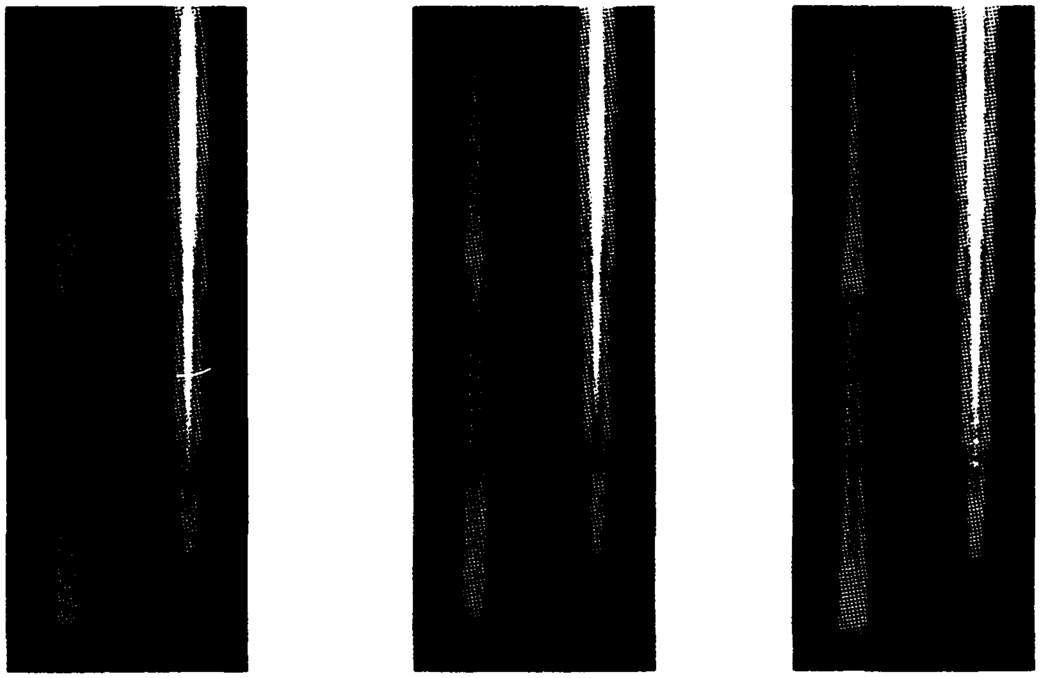
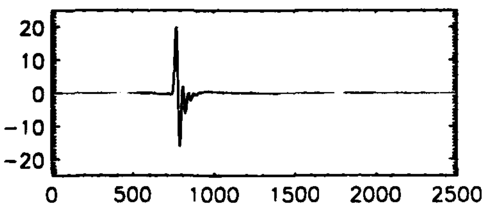


Figure 9. Transformed surface velocity, as a function of *m* and *n*.

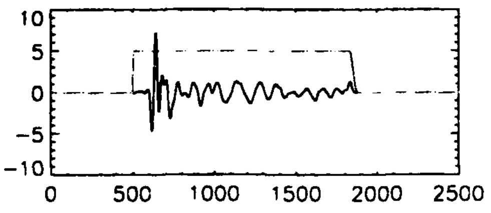


(a) Windowed (b) Experiment (c) Computed results

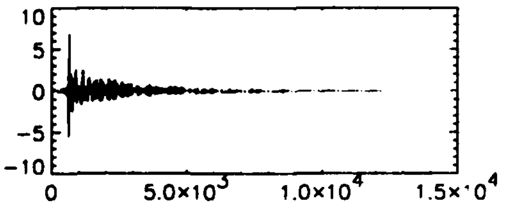
Figure10. Comparison of experimental results with windowed and unwindowed computational results.



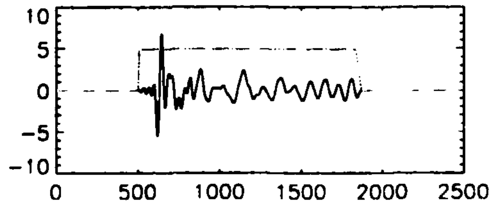
(a) Reference signal



(b) Experimental echo



(c) Computed time series



(d) Windowed time series

Figure 11. Time domain processing of computational data.

APPENDIX A: LISTINGS OF PROGRAMS

The program code makes use of a number of built-in PV-WAVE functions or procedures. A brief functional summary of the PV- WAVE procedures used in our visualizations is given below. These summaries are extracted with permission from the PV-WAVE Technical Reference Manual. In each case, the syntax of the function or procedure is given, with a brief explanation of the purpose of the routine.

Array creation routines

BINDGEN(Dim_1,...,Dim_n)	Byte array, each element its subscript.
BYTARR(Dim_1,...,Dim_n)	Returns a byte vector or array.
COMPLEXARR(Dim_1,...,Dim_n)	Complex single-precision vector or array.
FINDGEN(Dim_1,...,Dim_n)	Floating array, each element its subscript.
FLTARR(Dim_1,...,Dim_n)	Single-precision floating vector or array.
INDGEN(Dim_1,...,Dim_n)	Integer array, each element its subscript.
INTARR(Dim_1,...,Dim_n)	Returns a integer vector or array.
LONARR(Dim_1,...,Dim_n)	Returns longword integer vector or array.
REPLICATE(Value,Dim_1,...,Dm_n)	Forms new array filled with Value.

Array manipulation routines

MAX(Array[,Max_Subscript])	Finds the maximum element of an array.
MIN(Array[,Min_Subscript])	Finds the minimum element of an array.
REBIN(Array,Dim_1,...,Dim_n)	Resamples array to given dimensions.
REFORM(Array,Dim_1,...,Dim_n)	Reformats array without changing contents.
SHIFT(Array,S_1,...,S_n)	Shifts the elements of an array.
TRANSPOSE(Array)	Transposes an array.

Data conversion routines

BYTSCL(Array)	Scales and converts the array to the byte type.
FIX(Expr[,Offset[,Dim_1,...,Dim_n]])	Converts parameter to integer type.
STRING($Expr_1$,...,$Expr_n$)	Converts parameter to string type.

File manipulation routines

CLOSE[,$Unit_1$,...,$Unit_n$]	Closes one or more files.
FREE_LUN,$Unit_1$,...,$Unit_n$)	Deallocates one or more files.
GET_LUN,Unit	Reserves a file unit.
OPENR,Unit,File	Opens a file for reading access only.
OPENW,Unit,File	Opens a new file for writing access.

General graphics routines

MOVIE,Images[,Rate]	Cycles images stored in 3D array.
PLOTS,X[,Y[,Z]]	Draws lines (vectors) and points.
SET_PLOTS,Device	Specifies graphics device.
XYOUTS,X,Y,String	Sends text to selected graphics device.

General Mathematical functions

ABS(X)	Absolute value.
CONJ(X)	Complex conjugate.
FFT(Array,Direction)	Fast Fourier transform.

Image display routines

TV,Image[,X,Y[,Channel]]	Displays an image on the display screen.
TVSCL,Image[,X,Y[,Channel]]	Scales and displays an image.

Image processing routines

FFT(Array,Direction)	Fast Fourier transform.

Input and output routines

ASSOC(Unit,Array_structure[,Offset])	Associates variable with file structure.
PRINT,$Expr_1$,...,$Expr_n$)	Prints to the standard ouput stream.
READ,Var_1,...,Var_n)	Reads from the standard input stream.
READF,Unit,Var_1,...,Var_n)	Reads from the specified file unit.
READU,Unit,Var_1,...,Var_n)	Reads unformatted input.

Plotting routines

OPLOT,X[,Y]	Plots vector arguments over old axis.
PLOT,X[,Y]	Plots vector arguments.

Programming routines

HAK	"Hit any key to continue" function.
WAIT,Seconds	Delays program execution.

String processing routines

STRMID(Expr,First_Character,Length)	Extracts substring of string expression.
STRTRIM(String,[flag])	Removes leading and/or trailing blanks.

Transcendental mathematical functions

ALOG10(X)	Base 10 logarithm.
COS(X)	Cosine.
SIN(X)	Sine.

Window routines.

WINDOW[,Window_Index]	Creates a workstation window.
WSET[,Window_Index]	Selects the current window.

A list of the Utility and Application `*.pro` files follows, after which the actual programs and example output, where appropriate, are given. In the programs, any line or portion of a line beginning with a semicolon is treated as a comment.

Utility routines: Commented program code included

```
convffb.pro
convbco.pro
convsurb.pro
rdhdr.pro
grabff.pro
grabsur.pro
hardcopy.pro
closeit.pro
```

Application routines: Commented program code and example output included

```
ff3d.pro
plotsur.pro
envel pro
compff_m.pro
fig8.pro
window.pro
```

```
;convffb.pro
;Last modification: 20 April 92

;-----------------------------------------------------------
;This program takes a binary far-field pressure (.Ff#) file
;and produces an equivalent PV-Wave (.fw#) file.
;After this conversion, the .ff# is not needed by PV-Wave.
;-----------------------------------------------------------

; Select the data set

fname=string(replicate(32b,20))
print,'Input job name - no extension'
read,fname
print,'Input incidence angle'
read,iinc
case iinc of
    0:begin
        extension='.ff0'
        end
    45:begin
        extension='.ff4'
        end
    90:begin
        extension='.ff9'
        end
    135:begin
        extension='.ff3'
        end
    180:begin
        extension='.ff8'
        end
    endcase
fullname=fname+extension

get_lun,iunit
openr,iunit,fullname,/f77_unformatted
jobname=string(replicate(32b,8))
comment=string(replicate(32b,80))
intrec=lonarr(10)
rrec1=fltarr(10)
rrec2=fltarr(10)

; Although the header information is read from the data file,
; it is not stored.  The header information from the .bco file
; is used.

readu,iunit,jobname
print,'Reading the following data file: ',fullname
print,jobname
readu,iunit,comment
print,comment
readu,iunit,intrec
print,intrec
```

```
readu,iunit,rrecl
print,rrecl
readu,iunit,rrec2
print,rrec2
print,intrec(0),' ka values from = ',string(rrecl(0))
print,' in steps of ',string(rrecl(1))
print,intrec(1),' different patterns'
print,intrec(2),' theta incidence angles from ',rrecl(2)
print,' in steps of ',rrecl(3)

; Next, read the far-field pressure data
; data = complexarr(nka,nharms,nobs,isymm)
; assumes coefficients read as a block

vvector=complexarr(intrec(6))
data=complexarr(intrec(0),intrec(5),intrec(6),intrec(7))
for i=0,(intrec(0)-1) do begin
    for l=0,(intrec(5)-1) do begin
        for m=0,(intrec(7)-1) do begin
            readu,iunit,vvector
            data(i,l,*,m)=vvector
            endfor
        endfor
    endfor
close,iunit
print,'Finished reading the far-field pressure'

; Next, write the far-field data out to an unformatted
; PV-Wave file

case iinc of
    0:begin
        extension='.fw0'
        end
    45:begin
        extension='.fw4'
        end
    90:begin
        extension='.fw9'
        end
    135:begin
        extension='.fw3'
        end
    180:begin
        extension='.fw8'
        end
    endcase
outname=fname+extension

get_lun,junit
openw,junit,outname
al=assoc(junit,complexarr(intrec(0),intrec(5),intrec(3),$
intrec(7)))
al(0)=data
```

```
free_lun,iunit
free_lun,junit

print,'Finished writing the far-field data'
print,'Finished everything'
end
  1
```

```
;convbco.pro
;Last modification: 20 April 92

;-------------------------------------------------------------
;This program takes the binary .bco file and produces two
;ASCII PV-Wave files:
; .hdr - contains all the parameters of the job
; .wco - has the axial and radial coordinates of
;        the scatterer.
;After this conversion, the .bco file is not
;needed by PV-Wave.
;-------------------------------------------------------------

; Select the data set

fname=string(replicate(32b,20))
print,'Input job name - no extension'
read,fname

; Open the file with header and coordinate data (.bco file)
; Then, define some variables and read the header

get_lun,iunit
openr,iunit,fname+'.bco',/f77_unformatted
jobname=string(replicate(32b,8))
comment=string(replicate(32b,80))
intrec=lonarr(10)
rrec1=fltarr(10)
rrec2=fltarr(10)
readu,iunit,jobname
print,'Reading the following data file: ',fname
print,jobname
readu,iunit,comment
print,comment
readu,iunit,intrec
print,intrec
readu,iunit,rrec1
print,rrec1
readu,iunit,rrec2
print,rrec2
print,intrec(0),' ka values from = ',string(rrec1(0))
print,' in steps of ',string(rrec1(1))
print,intrec(1),' different patterns'
print,intrec(2),' theta incidence angles from ',rrec1(2)
print,' in steps of ',rrec1(3)

; Now write the header info to a formatted PV-Wave file

get_lun,junit
openw,junit,fname+'.hdr'
printf,junit,jobname
printf,junit,comment
printf,junit,format='(10i5)',intrec
printf,junit,format='(5g10.4/5g10.4)',rrec1
```

```
printf,junit,format='(5g10.4/5g10.4)',rrec2
free_lun,junit
print, 'Finished with the header info'

; Next, read the coordinates

coord=fltarr(2,intrec(4))
junk=fltarr(intrec(4))
for i=0,1 do begin
    readu,iunit,junk
    coord(i,*)=junk
    endfor
print,coord
free_lun,iunit

; Now write the coords to a formatted PV-Wave file

get_lun,junit
openw,junit,fname+'.wco'
printf,junit,coord
free_lun,junit
print,'Finished with the coordinates'

print,'Finished everything'
end
 1
```

```
;convsurb.pro
;Last modification: 20 April 92

;---------------------------------------------------------
;This program  takes a binary surface data file
;(either surface pressure, .sp#, or normal velocity, .nv#)
;and produces an equivalent, binary PV-Wave file
;(either .pw# for surface pressure or .vw# for normal velocity).
;After this conversion, the .nv# or .sp# file is not needed
;by PV-Wave.
;---------------------------------------------------------

; Select the data type and set

fname=string(replicate(32b,20))
surtype=' '
print,'Input job name - no extension'
read,fname
print,'Input p for pressure or v for velocity'
read,surtype
case surtype of
    'p':begin
        stype='.sp'
        otype='.pw'
        words='surface pressure'
        end
    'v':begin
        stype='.nv'
        otype='.vw'
        words='normal velocity'
        end
    endcase
print,'Input incidence angle'
read,iinc
case iinc of
    0:begin
        extension=stype+'0'
        oextension=otype+'0'
        end
    45:begin
        extension=stype+'4'
        oextension=otype+'4'
        end
    90:begin
        extension=stype+'9'
        oextension=otype+'9'
        end
    135:begin
        extension=stype+'3'
        oextension=otype+'3'
        end
    180:begin
        extension=stype+'8'
        oextension=otype+'8'
        end
    endcase
fullname=fname+extension

; Open the file
; Then, define some variables and read the header
; Header is read from the data file, but is not
; written.  The .hdr file is generated with
; convbco.pro

get_lun,iunit
openr,iunit,fullname,/f77_unformatted
jobname=string(replicate(32b,8))
comment=string(replicate(32b,80))
intrec=lonarr(10)
rrecl=fltarr(10)
rrec2=fltarr(10)
readu,iunit,jobname
print,'Reading the following data file: ',fullname
print,jobname
readu,iunit,comment
print,comment
readu,iunit,intrec
print,intrec
readu,iunit,rrecl
print,rrecl
readu,iunit,rrec2
print,rrec2
print,intrec(0),' ka values from = ',string(rrecl(0))
print,' in steps of ',string(rrecl(1))
print,intrec(1),' different patterns'
print,intrec(2),' theta incidence angles from ',rrecl(2)
print,' in steps of ',rrecl(3)

; Next, read the surface data
; dumvector=complexarr(nka,nharms,nareas,isymm)
; assumes coefficients read as a block

surf=complexarr(intrec(0),intrec(5),intrec(3),intrec(7))
dumvector=complexarr(intrec(3))
for i=0,(intrec(0)-1) do begin
    for l=0,(intrec(5)-1) do begin
        for m=0,(intrec(7)-1) do begin
            readu,iunit,dumvector
            surf(i,l,*,m)=dumvector
            endfor
        endfor
    endfor
free_lun,iunit
print,'Finished reading the '+words

; Next, write the surface data out to an unformatted
; PV-Wave file

```

```
outname=fname+oextension

get_lun,junit
openw,junit,outname
a1=assoc(junit,complexarr(intrec(0),intrec(5),intrec(3),$
intrec(7)))
a1(0)=surf
free_lun,junit

print,'Finished writing the '+words
print,'Finished everything'
end
```

```
pro rdhdr,filename=fname
;Last modification: 20 April 92

;----------------------------------------------------------
;This program reads header from a data set with the same
;job name
;----------------------------------------------------------

common header,jobname,comment,$
nka,npatts,nthetainc,nareas,ncoords,nharms,nobs,isymm,$
kastart,kainc,thetaincstart,thetaincinc,phiincstart,$
phiincinc,thetaobsstart,thetaobsinc,$
rhof,cf,rhom,young,nu,eta

; First, some definitions

jobname=string(replicate(32b,8))
comment=string(replicate(32b,80))
intrec=lonarr(10)
rrec1=fltarr(10)
rrec2=fltarr(10)

; Now, read the header file

get_lun,junit
openr,junit,fname+'.hdr'
readf,junit,jobname        ; 8 character name of run
readf,junit,comment        ; 80 characters (20 words) for comments
; description, etc.
readf,junit,format='(10i5)',intrec
readf,junit,format='(5g10.4/5g10.4)',rrec1
readf,junit,format='(5g10.4/5g10.4)',rrec2
free_lun,junit

; Give the header info some more meaningful names
; First the integer record

nka=fix(intrec(0))         ; number of ka values
npatts=fix(intrec(1))      ; number of ff patterns
nthetainc=fix(intrec(2))   ; number of theta incident angles
nareas=fix(intrec(3))      ; number of areas (rings)
ncoords=fix(intrec(4))     ; number of coordinates
nharms=fix(intrec(5))      ; number of azimuthal harmonics
nobs=fix(intrec(6))  ; number of observation angles in ff patterns
isymm=fix(intrec(7))       ; symmetry flag, 1-yes, 2-no

; Now, the first real record

kastart=rrec1(0)
kainc=rrec1(1)
thetaincstart=rrec1(2)
thetaincinc=rrec1(3)
phiincstart=rrec1(4)
phiincinc=rrec1(5)
```

```
thetaobsstart=rrec1(6)
thetaobsinc=rrec1(7)

; the rest of rrec1 is currently not used
; Finally, the second real record

rhof=rrec2(0)               ; fluid density
cf=rrec2(1)                 ; sound speed in fluid
rhom=rrec2(2)               ; density of shell
young=rrec2(3)              ; Young's modulus of shell
nu=rrec2(4)                 ; Poisson's ratio of shell
eta=rrec2(5)                ; damping factor

; the rest of rrec2 is currently not used
; Print the basic information about this data set

print,'Jobname is ',jobname
print,'Comments: ',comment
print,'There are ',nka,' ka values from ',string(kastart)$
,' in steps of ',string(kainc)
print,'The spectral variable is ka'
print,'There are ',npatts,' ff patterns'
print,'          ',nareas,' areas or rings'
print,'          ',ncoords,' coordinate values'
print,'          ',nthetainc,' theta incident angles'
print,'There are ',nthetainc,' theta incidence angles from '$
,thetaincstart,' in steps of ',thetaincinc
print,'          ',nobs,$
' theta observation angles npff pattern from ',$
thetaobsstart,' in steps of ',thetaobsinc
print,'The fluid density is ',rhof
print,'The sound speed in the fluid is ',cf
print,'The density of shell is ',rhom
print,'The Youngs modulus of shell is ',young
print,'Poissons ratio for the shell is ',nu
print,'The damping factor is ',eta

end
```

```
;grabff.pro
;Last modification: 20 April 92

;---------------------------------------------------------
;This program reads in PV-Wave binary far-field file
;(.fw#) placing all far-field data in memory for use as
;data.
;---------------------------------------------------------

common header,jobname,comment,$
nka,npatts,nthetainc,nareas,ncoords,nharms,nobs,isymm,kastart,$
kainc,thetaincstart,thetaincinc,phiincstart,phiincinc,$
thetaobsstart,thetaobsinc,rhof,cf,rhom,young,nu,eta

jobname='         '
pathname=' '
print,'input jobname (no extension) '
read,jobname
print,'input pathname including trailing /'
read,pathname
fullname=pathname+jobname

; read vital parameters from .hdr file

rdhdr,filename=fullname
print,'Input incidence angle'
read,iinc
case iinc of
    0:begin
        extension='.fw0'
        end
    45:begin
        extension='.fw4'
        end
    90:begin
        extension='.fw9'
        end
    135:begin
        extension='.fw3'
        end
    180:begin
        extension='.fw8'
        end
    else:print,'Invalid angle'
    endcase
fullname=fullname+extension

; Open the file, then read in far-field data

get_lun,iunit
openr,iunit,fullname
aa=assoc(iunit,complexarr(nka,nharms,nobs,isymm))
data=aa(0)

```

```
; This section of the code recombines the harmonic
; components for each ka.  A default increment in
; phi of 30 degrees is used.
; Recombined data are held in the variable npff.

deltaphi=30
numphi=1+fix(360./deltaphi)
angles=deltaphi*(!pi/180.)*findgen(numphi)
ivect=indgen(nharms)
cosangle=transpose(cos(ivect#angles))
sinangle=transpose(sin(ivect#angles))
npff=complexarr(numphi,nobs,nka)
for kabin=0,nka-1 do begin
    ctemp=complexarr(numphi,nobs)
    if isymm eq 1 then ctemp=cosangle#reform(data(kabin,*,*,0))
    if isymm eq 2 then ctemp=cosangle#reform(data(kabin,*,*,0)) $
    +sinangle#reform(data(kabin,*,*,1))
    npff(*,*,kabin)=ctemp
    endfor
loadct,5
free_lun,iunit

; This section of code produces three color images
; of the npff data; target strength in db, magnitude,
; and phase.  The phi observation angle is fixed at
; 0 degrees.  The range for target strength is [-30,30].
; The range for magnitude is [0,max(mag)].  The range
; for phase is [-180,180].
; In each case, the entire theta range has been
; reconstructed [0,360].  The x-axis corresponds to
; the theta observation angle; the y-axis to the
; ka range.

xsz=2*nobs-1
ysz=nka
halfway=(numphi-1)/2

;  Recombine the full theta observation range

var=fltarr(xsz,ysz)
var(0:nobs-1,*)=abs(npff(0,*,*))
var(nobs:xsz-1,*)=abs(reverse(reform(npff(halfway,1:nobs-1,*)),1))

; Calculate the target strength in dB

ts=20*alog10(var)
tsimg=bytscl(ts,min=-30,max=30)

; Calculate the magnitude and phase

magimg=bytscl(var,min=0)
phase=fltarr(xsz,ysz)
phase(0:nobs-1,*)=(180./!pi)*atan(imaginary(npff(0,*,*)),$
(float(npff(0,*,*))))
```

```
phase(nobs:xsz-1,*)=reverse(reform((180./!pi)*$
atan(imaginary(npff(halfway,1:nobs-1,*)),float(npff(halfway,$
1:nobs-1,*)))),1)
phaseimg=bytscl(phase,min=-180,max=180)

; Set up the plotting window

window,/free,xpos=200,ypos=200,xsize=700,ysize=700
tv,tsimg,100,100
tv,magimg,270,100
tv,phaseimg,440,100
xyouts,/device,100,450,'Target Strength'
xyouts,/device,270,450,'FF Magnitude'
xyouts,/device,440,450,'FF Phase'
title='FAR-FIELD DATA: '+ comment
xyouts,/device,100,520,title
title2='Incidence angle' + string(iinc)
xyouts,/device,150,500,title2
xyouts,/device,400,650,fullname

end
```

```
;grabsur.pro
;Last modification: 20 April 92

;-----------------------------------------------------------
;This program reads in a PV-Wave binary normal velocity (.vw#)
;or surface pressure(.pw#) file, placing all surface data
;in memory for use as sur(nka,numphi,ncoords).
;-----------------------------------------------------------

common header,jobname,comment,$
nka,npatts,nthetainc,nareas,ncoords,nharms,nobs,isymm,$
kastart,kainc,thetaincstart,thetaincinc,phiincstart,$
phiincinc,thetaobsstart,thetaobsinc,rhof,cf,rhom,young,$
nu,eta

fname='         '
pathname=' '
print,'input jobname (no extension)'
read,fname
print,'input pathname including trailing /'
read,pathname
fname=pathname+fname

; Read essential parameters from .hdr

rdhdr,filename=fname
print,'Input incidence angle'
read,iinc
surtype=' '
print,'Do you want surface pressure(p) or velocity(v)?'
read,surtype
if surtype eq 'v' then begin
    title='NORMAL VELOCITY MAGNITUDE'
    stype='.vw'
    endif
if surtype eq 'p' then begin
    title='SURFACE PRESSURE MAGNITUDE'
    stype='.pw'
    endif
case iinc of
    0:begin
        extension=stype+'0'
        end
    45:begin
        extension=stype+'4'
        end
    90:begin
        extension=stype+'9'
        end
    135:begin
        extension=stype+'3'
        end
    180:begin
        extension=stype+'8'
        end
    endcase
fullname=fname+extension

; Open the file

get_lun,iunit
openr,iunit,fullname,/f77_unformatted
aa=assoc(iunit,complexarr(nka,nharms,ncoords,isymm))
data=aa(0)
free_lun,iunit

; This section of the code recombines harmonics for each
; ka at a default increment in phi of 30 degrees.

deltaphi=30
numphi=1+fix(360./deltaphi)
angles=deltaphi*(!pi/180.)*findgen(numphi)
ivect=indgen(nharms)
cosangle=transpose(cos(ivect#angles))
sinangle=transpose(sin(ivect#angles))
sur=complexarr(nka,numphi,ncoords)
ctemp=complexarr(numphi,ncoords)
for kabin=0,nka-1 do begin
    if isymm eq 1 then ctemp=cosangle#reform(data(kabin,*,*,0))
    if isymm eq 2 then ctemp=cosangle#reform(data(kabin,*,*,0)) $
    +sinangle#reform(data(kabin,*,*,1))
    sur(kabin,*,*)=ctemp
    endfor

; Draw labeled pictures.
; The 'Persian rug' plot is for a fixed ka (default nka/2).
; The 'standing wave' plot is for a fixed phi obs angle of 0 deg.

binno=nka/2
phicut=0
x=findgen(nka)*kainc+kastart

; Draw labeled picture

print,min(abs(sur)),max(abs(sur))
print,'input maximum value'
read,maxval
window,/free,xpos=100,ypos=100,xsize=900,ysize=650
loadct,5
y_scale=bindgen(1,202)
tv,congrid(y_scale,30,331),800,70
x4=[0,0]
y=[0,maxval]
plot,x4,y,xstyle=4,ystyle=1,pos=[800,70,830,401],/dev,$
/nodata,/noerase,yticks=7
tv,bytscl(congrid(abs(reform(sur(binno,*,*))),20*numphi,288,$
/interp),min=0,max=maxval),90,70
y=[0,1.]
```

```
x2=[0,360]
plot,x2,y,xstyle=1,ystyle=1,xticks=6,yticks=4,/nodata,$
/noerase,/dev,pos=[90,70,20*numphi+90,358]
xyouts,/device,210,500,title,size=2
xyouts,/device,300,480,'minval='+string(min(abs(sur)))
xyouts,/device,300,465,'maxval='+string(max(abs(sur)))
tv,bytscl(transpose(congrid(reform(abs(sur(*,phicut,*))),$
nka,288,/interp)),min=0,max=maxval),425,70
y=[0,1.]
x3=[min(x),max(x)]
plot,y,x3,xstyle=1,ystyle=1,xticks=4,yticks=11,/dev,$
/nodata,/noerase,pos=[425,70,713,nka+70]
xyouts,/device,240,570,'incidence angle = '+string(iinc)
xyouts,/device,240,620,fullname,size=2
xyouts,/device,120,425,'For ka = '+strtrim(string(x(binno)),2)
xyouts,/device,450,425,'For phibin = '+strtrim(string(phicut),2)
xyouts,/device,150,25,'Phi'
xyouts,/device,45,125,'Normalized axial distance',orientation=90
xyouts,/device,445,25,'Normalized axial distance'
xyouts,/device,380,200,'ka',orientation=90

end
```

```
pro hardcopy,FILENAME=filename,BITS=bits,XSIZE=xsize,YSIZE=ysize
;Last modification: 24 Mar 92

;-----------------------------------------------------------
;This procedure sets the display parameters to generate
;an (encapulated) Postscript file for producing hardcopy
;output. Sets default values.
;-----------------------------------------------------------

if n_elements(filename) eq 0 then filename='junk.eps'
if n_elements(bits) eq 0 then bits=8
if n_elements(xsize) eq 0 then xsize=5.
if n_elements(ysize) eq 0 then ysize=5.

set_plot,'ps'
device,xoffset=0,yoffset=0,XSIZE=xsize,YSIZE=ysize,/inches ;sets
;bounding box
device,/color  ; put it out as color Postscript (delete for b&w)
device,bits_per_pixel=bits,filename=filename,/encapsulated

; If you want to go directly to the QMS color printer
; use the following settings:

;set_plot,'ps'
;device,xoffset=2.,yoffset=3.,xsize=2.,ysize=3.,/inches
;device,/color,bits_per_pixel=8
;device,filename='dcopy.ps'

end
```

```
pro closeit
;Last modification: 21 April 92

;-----------------------------------------------------------
;This program closes the hardcopy file and sets the display
;back to 'x' window, replace 'x' with default driver on system
;-----------------------------------------------------------

device,/close_file ; close the file, so it can be sent to
; the printer
set_plot,'x'     ; redirect the output to the 'x' window driver

end
```

```
;ff3d.Pro
;Last modification: 24 Mar 92

;-----------------------------------------------------------
; This program reads in PV-Wave binary far-field file
; (.fw#), generates a 3-d display of far-field pressure for
; user-defined increments in ka, and displays the result as a
; movie
;-----------------------------------------------------------

common header,jobname,comment,$
nka,npatts,nthetainc,nareas,ncoords,nharms,nobs,isymm,$
kastart,kainc,thetaincstart,thetaincinc,phiincstart,$
phiincinc,thetaobsstart,thetaobsinc,rhof,cf,rhom,young,nu,$
eta


jobname='           '
pathname=' '
print,'input jobname (no extension)'
read,jobname
print,'input pathname including trailing /'
read,pathname
fullname=pathname+jobname
rdhdr,filename=fullname
print,'Input incidence angle'
read,iinc
case iinc of
    0:begin
        extension='.fw0'
        end
    45:begin
        extension='.fw4'
        end
    90:begin
        extension='.fw9'
        end
    135:begin
        extension='.fw3'
        end
    180:begin
        extension='.fw8'
        end
    endcase
fullname=fullname+extension

get_lun,iunit
openr,iunit,fullname
aa=assoc(iunit,complexarr(nka,nharms,nobs,isymm))
data=aa(0)
free_lun,iunit

; This section of the code recombines harmonics for a
; default phi increment of 30 degrees. Note:  a finer
; increment may be desired to eliminate plotting
; artifacts.
; define some variables

deltaphi=30
numphi=1+fix(360./deltaphi)
angles=deltaphi*(!pi/180.)*findgen(numphi)
ivect=indgen(nharms)
cosangle=transpose(cos(ivect#angles))
sinangle=transpose(sin(ivect#angles))
npff=complexarr(numphi,nobs,nka)

; form npff for each phi angle

for kabin=0,nka-1 do begin
    ctemp=complexarr(numphi,nobs)
    if isymm eq 1 then ctemp=cosangle# $
    reform(data(kabin,*,*,0))
    if isymm eq 2 then ctemp=cosangle# $
    reform(data(kabin,*,*,0)) +sinangle# $
    reform(data(kabin,*,*,1))
    npff(*,*,kabin)=ctemp
    endfor

; generate frames (default of 5 )

nframes=5
step=fix(nka/nframes)
xp=fltarr(nobs,numphi)
yp=fltarr(nobs,numphi)
zp=fltarr(nobs,numphi)
indtheta=indgen(nobs)
indphi=indgen(numphi)
unity=replicate(1,numphi)

; the selection of the radius, a,  is arbitrary, but
; it does affect the size of the display

a=5.
tang=!pi*indtheta/(nobs-1)    ; generate a vector of theta's
pang=2*!pi*indphi/(numphi-1)  ; same for phi's
zp=a*cos(tang)#unity
factor=a*sin(tang)
xp=factor#cos(pang)
yp=factor#sin(pang)
sh=bytarr(nobs,numphi)        ; this holds the (bytscaled) target
; strength values
newimg=bytarr(370,365,nframes+1)

window,0,xpos=350,ypos=300,xsize=370,ysize=365
loadct,5
kaval=findgen(nka)*kainc+kastart
for j=0,nframes do begin      ; frequency loop
    k=j*step
    sh=bytscl(20*alog10(transpose(abs(npff(*,*,k)))),$
    min=-40,max=40)

    ; the next routine tends to choke on a number of degenerate
    ; polygons, which may cause some artifacts, but the
    ; routine does not bomb and the results are useful as is

    shade_surf_irr,sh*zp,sh*xp,sh*yp,shades=sh,$
    xrange=[-1000,1000],yrange=[-1000,1000],zrange=[-1000,1000]
    xyouts,0.4,0.8,'ka = '+strtrim(string(kaval(k))),$
    size=1,/normal
    wait,0.0001
    newimg(*,*,j)=tvrd(0,0,370,365)
    endfor

; redisplay the frames as a movie

movie,newimg,order=0

; make a hard copy of any frame of interest

;hardcopy,file='clb93d#18.eps',xsize=3.70,ysize=3.65
;tv,newimg(*,*,18)
;closeit

end
```

```
;plotsur.pro
;Last modification: 21 April 92


;-----------------------------------------------------------
;This program makes an animated multi-color plot showing how
;surface pressure or normal velocity vary with axial node
;number and frequency. It assumes that grabsur.pro has been
;run and sur(nka,numphi,ncoords) is in memory
;-----------------------------------------------------------

common header,jobname,comment,$
nka,npatts,nthetainc,nareas,ncoords,nharms,nobs,isymm,$
kastart,kainc,thetaincstart,thetaincinc,phiincstart,phiincinc,$
thetaobsstart,thetaobsinc,rhof,cf,rhom,young,nu,eta

window,/free
plot,sur(0,0,*),ystyle=1,xstyle=1,yrange=[0,maxval],/nodata, $
xtitle='Axial bin number',ytitle='Magnitude'
for i=0,nka-1 do begin
    oplot,abs(sur(i,0,*)),color=i
    wait,.02
    endfor


end
```

```
;envel.pro
;Last modification: 15 May 92

;-------------------------------------------------------------
;This program generates a set of overlaid spectral plots from
;supposedly equivalent solutions generated by different codes,
;allows the user to select a subset of the solutions, and
;produces a mean and envelope that bound the variations within
;the data sets selected.
;Note:  This program assumes the data to be compared has been
;read in prior to the execution of envel.pro.  The data for
;the Benchmark exercise was stored in variables named amag0
;through wmag0, all of which were of the size (nobs,nkas). The data
;sets were reduced by the selecting the phi observation angle prior
;to execution.
;The example given was produced with modified versions of this
;routine.
;-------------------------------------------------------------
;
;First set some default plotting styles
;
!x.style=1
!y.style=1
!x.ticks=6
!y.ticks=6
;
id=' '
print,'Enter index of theta angle desired'
if bmname ne '4a' and bmname ne '4b' then begin
    print,'0=0obs, 18=45obs, 36=90obs, 54=135obs, 72=180obs'
    fact=2.5
    endif else begin
    print,'0=0obs,15=45obs,30=90obs,45=135obs, 60=180obs'
    fact=3.0
    endelse
read,tangle
;
print,'Enter number of data sets available'
read,nsets
print,nsets
print,'Enter number of ka values'
read,nkas
;
;Set up x-axis scale
x=findgen(nkas)*.01+.2
if (bmname eq '4a' or bmname eq '4b') then x=findgen(nkas)*.0094+.397
;
;Determine max(x) as legend positioning is tied to this value
maxx=max(x)
if(bmname eq '1a')then nkas=330  ; special case
;
;The spectral plots are saved in the array results.
results=fltarr(nsets,nkas)
results(0,*)=amag0(tangle,0:nkas-1)
results(1,*)=cmag0(tangle,0:nkas-1)
results(2,*)=smag0(tangle,0:nkas-1)
results(3,*)=wmag0(tangle,0:nkas-1)
if nsets ge 5 then results(4,*)=nmag0(tangle,0:nkas-1)
if nsets ge 6 then results(5,*)=fmag0(tangle,0:nkas-1)
resultsave=results

; The y-axis is autoscaled to 1.1*max of the data.
maxdata=1.1*max(results)
;
; The following statements set up line types &
; colors and the legend on raw data plot.

ltype=intarr(nsets)
ltype(0:3)=[0,0,0,4]
colors=intarr(nsets)
colors(0:3)=[200,26,164,200]
label=strarr(nsets)
label(0)='1 - axsar'
label(1)='2 - chief'
label(2)='3 - sara'
label(3)='4 - wascat'
if nsets ge 5 then begin
    label(4)='5 - nashua'
    ltype(4)=4
    colors(4)=26
    endif
if nsets ge 6 then begin
    ltype(5)=4
    colors(5)=164
    label(5)='6 - fist'
    endif
;These set up the same for the envelope plot.
lbl=['average','min / max']
ltyp=0
clr=[164,200]
;
window,/free,xsiz=625,ysiz=600,xpos=0,ypos=250
loadct,12
!x.title='ka'
!y.title='NPFF, mag'
plot,x,results(0,*),yrange=[0,maxdata],color=colors(0)
for i=1,nsets-1 do oplot,x,results(i,*),color=colors(i),$
linestyle=ltype(i)
legend,label,colors,ltype,psym,.7*maxx,.87*maxdata,maxdata/40.
print,'Input problem identifier; e.g. BM1B 45 INC'
read,id
id=strcompress(strupcase(id+' , '+string(fix(fact*tangle))+' obs '))
xyouts,.6,.90,/normal,id,color=200,size=1.2
xyouts,.6,.87,/normal,'RAW DATA',color=200,size=1.2
ans='y'
while ans eq 'y' do begin
    maxdiff=0.
    setid=' '
    results=resultsave
    ;
    ;User picks how many and which data sets to include in
    ;the envelope. The user can chose to reprocess the envelope.
    ;
    print,'how many data sets do you want to include'
    read,numin
    if numin eq nsets then setid='ALL DATA SETS'
    if numin ne nsets then begin
        sets=intarr(numin)
        print,'which data sets do you want to include',$
        '1 - nsets possible'
        read,sets
        print,'you have asked to include sets',sets
        for i=0,numin-1 do setid=setid+string(sets(i))
        for i=0,numin-1 do sets(i)=sets(i)-1
        results=results(sets,*)
        endif
    average=avg(results,0)
    window,/free,xsiz=625,ysiz=600,xpos=625,ypos=250
    mini=min(results)
    maxdum=fltarr(nkas)
    mindum=fltarr(nkas)
    for i=0,nkas-1 do begin
        maxdum(i)=max(results(*,i))
        mindum(i)=min(results(*,i))
        endfor
    maxd=1.2*max(maxdum)
    plot,x,(average),/nodata,yrange=[0,maxdata]
    oplot,x,(average),color=164
    oplot,x,(maxdum)
    oplot,x,(mindum)
    legend,lbl,clr,ltyp,psym,.7*maxx,.8*maxdata,.3
    xyouts,.6,.85,/normal,strcompress(setid),color=200,siz=1.2
    xyouts,.6,.90,/normal,id,color=200,siz=1.2
    maxdiff=max(maxdum-mindum)
    print,'Maximum difference = ',maxdiff,' at ',$
    x(where(maxdum-mindum eq maxdiff))
    ;oplot,x,ntruth(0,*),color=100
    print,'Do you want to reprocess, y or n'
    read,ans
    endwhile
end
```

```
pro compff_m
;
;Last modification:  19 May 1992
;
;------------------------------------------------------------
; This procedure plots the target strength image for two codes and
; plots the difference between the images.
; The difference is taken between dB values which have first been
; subjected to a user-specified threshold.
; The user is allowed interactive control over the dynamic range
; of the images and the difference image.
;
; Note: The procedure assumes npff_m.pro has been compiled.
;------------------------------------------------------------

common header, jobname, comment, $
nka,npatts,nthetainc,nareas,ncoords,nharms,nobs,isymm,$
kastart,kainc,thetaincstart,thetaincinc,phiincstart,phiincinc,$
thetaobsstart,thetaobsinc,rhof,cf,rhom,young,nu,eta
;
common share1, npff, numphi, diff
;
; Get the first set of data
;
print,'Prompting for the threshold value in db'
read,thresh_db
print,'Prompting for dynamic range desired for difference'
read,dmin,dmax
print,'Prompting for the first far-field data file.'
npff_m
npff1=abs(npff)
;npff1(where(abs(npff1) le thresh))=thresh
nka1=nka
;
print,'Prompting for the second far-field data file.'
npff_m
npff2=abs(npff)
;npff2(where(abs(npff2) le thresh))=thresh
;
xsz=2*nobs-1
ysz=nka
;
ysz1=nka1
;Calculate the target strengths
;
ansd='n'
anst='n'
ans='y'
repeat begin
    print,'Input the index of the phi angle (0 to 6).'
    read,phiinc
    halfway=(numphi-1)/2 + phiinc
    var1=fltarr(xsz,ysz1)
    var1(0:nobs-1,*)=(npff1(phiinc,*,*))
```

```
var1(nobs:xsz-1,*)=(reverse(reform(npff1(halfway,$
1:nobs-1,*)),1))
ts1=20*alog10(var1)
var2=fltarr(xsz,ysz)
var2(0:nobs-1,*)=(npff2(phiinc,*,*))
var2(nobs:xsz-1,*)=(reverse(reform(npff2(halfway,$
1:nobs-1,*)),1))
ts2=20*alog10(var2)
loadct,5
print,'max values',max(ts1),max(ts2),' min values',$
min(ts1),min(ts2)
print,'input dynamic range for ts pictures'
read,mints,maxts
top=202
print,'input number of colors on system'
read,topval
window,0,xsize=2*xsz,ysize=2*ysz,xpos=100,ypos=200,$
title='Set 1'
tv,rebin(bytscl(ts1,min=mints,max=maxts,top=topval),$
2*xsz,2*ysz1)
window,1,xsize=2*xsz,ysize=2*ysz,xpos=800,ypos=200,$
title='Set 2'
tv,rebin(bytscl(ts2,min=mints,max=maxts,top=topval),$
2*xsz,2*ysz)
window,5,xsize=100,ysiz=300,xpos=1125,ypos=550
y_scale=bindgen(1,topval)
tv,congrid(y_scale,30,250),45,30
x=[0,0]
y=[mints,maxts]
plot,x,y,xstyle=4,ystyle=1,pos=[45,30,75,280],/device,$
/nodata,/noerase,yticks=4
print,'hit when ready'
hak
repeat begin
    ts1(where(ts1 le thresh_db))=thresh_db
    ts2(where(ts2 le thresh_db))=thresh_db
    diff=ts1-ts2
    repeat begin
        loadct,11
        ;stretch,0,255
        window,2,xsize=2*xsz,ysize=2*ysz,xpos=450,ypos=200,$
        title='Difference'
        tv,rebin(bytscl(diff,min=dmin,max=dmax,top=topval),$
        2*xsz,2*ysz1)
        window,6,xsiz=100,ysiz=300,xpos=1125,ypos=200
        tv,congrid(y_scale,30,250),45,30
        x=[0,0]
        y=[dmin,dmax]
        plot,x,y,xstyle=4,ysyle=1,pos=[45,30,75,280],/device,$
        /nodata,/noerase,yticks=4,color=101
      print,'Do you want a new dynamic range for the difference'
        read,ansd
        if(ansd eq 'y') then begin
            print,'Input min and max desired'
```

```
                read,dmin,dmax
                endif
            endrep until ansd eq 'n'
        print,'Do you want another threshold value? (y/n)'
        read,anst
        if(anst eq 'y') then begin
            print,'Input new threshold value'
            read,thresh_db
            endif
        endrep until anst eq 'n'
    print,'Do you want another phi angle? (y/n)'
    read,ans
    endrep until ans eq 'n'
end
```

```
;fig8.pro
;Last modification: 20 Jul 92

;-----------------------------------------------------------
;This program generates and displays color surfaces
;which portray target strength as a function of frequency
;and azimuth
;-----------------------------------------------------------

common header,jobname,comment,$
nka,npatts,nthetainc,nareas,ncoords,nharms,nobs,isymm,$
kastart,kainc,thetaincstart,thetaincinc,phiincstart,$
phiincinc,thetaobsstart,thetaobsinc,$
rhof,cf,rhom,young,nu,eta

datapath='/data/schenck/dset2/'
jobname='          '
print,'input runname (without extension'
print,' assumed to be in /data/schenck/dset2)'
read,jobname

fullname=datapath+jobname
rdhdr,filename=fullname

print,'Input incidence angle'
read,iinc
case iinc of
    0:begin
        extension='.vw0'
        end
    45:begin
        extension='.vw4'
        end
    90:begin
        extension='.vw9'
        end
    135:begin
        extension='.vw3'
        end
    180:begin
        extension='.vw8'
        end
    endcase
fullname=fullname+extension

get_lun,iunit
openr,iunit,fullname
aa=assoc(iunit,complexarr(nka,nharms,ncoords,isymm))
vel=aa(0)
free_lun,iunit

window,2,xsize=50,ysize=512,xpos=150,ypos=300
loadct,11
cbar=bytarr(50,512)
```

```
for i=0,255 do cbar(*,i*2:i*2+1)=i
tv,cbar

nendnodes=12  ; presently not in header file
npts=nareas-2*nendnodes
mfact=5 ; multiplication factor for display
nfact=5  ; multiplication factor for display
window,4,xpos=250,ypos=375,xsize=mfact*npts,$
ysize=nfact*(2*nharms-1)

char='g'  ; a junk character

for l=0,0 do begin

    f=90+10*l
    if isymm eq 2 then begin
        vf=reform(vel(f,*,nendnodes:nendnodes+npts-1,*))
        vh=complexarr(2*nharms-1,npts)
        for h=-(nharms-1),nharms-1 do begin
            if h eq 0 then begin
                vh(h+nharms-1,*)=reform(vf(h,*,0))
                endif
            if h gt 0 then begin
                vh(h+nharms-1,*)=0.5*reform(vf(h,*,0))-com-
plex(0,1)*$
                reform(vf(h,*,1))
                endif
            if h lt 0 then begin
                vh(h+nharms-1,*)=0.5*reform(vf(-h,*,0))-com-
plex(0,1)*$
                reform(vf(-h,*,1))
                endif
            endfor
        endif else begin  ; to allow cosine only representation
        vf=reform(vel(f,*,nendnodes:nendnodes+npts-1))
        vh=complexarr(2*nharms-1,npts)
        for h=-(nharms-1),nharms-1 do begin
            if h eq 0 then begin
                vh(h+nharms-1,*)=reform(vf(h,*))
                endif
            if h gt 0 then begin
                vh(h+nharms-1,*)=0.5*reform(vf(h,*))
                endif
            if h lt 0 then begin
                vh(h+nharms-1,*)=0.5*reform(vf(-h,*))
                endif
            endfor
        endelse
    npts=47 ; ###  to force npts to be odd, not general!
    vh=vh(*,0:46) ; same

    kmat=complexarr(2*nharms-1,npts)
    sym=complexarr(2*nharms-1,npts)
    middle=(npts-1)/2
    for i=0,2*(nharms-1) do begin
        vect0=reform(vh(i,*))
        kmat(i,*)=fft(vect0,1)
        sym(i,middle)=kmat(i,0)
        unitv=complexarr(middle+1)
        unitv(0)=complex(1,0)
        unitv(1)=complex(cos(!pi*(npts-1)/npts),$
        sin(!pi*(npts-1)/npts))
        for j=1,middle do begin
            unitv(j)=unitv(1)*unitv(j-1)
            sym(i,middle+j)=unitv(j)*kmat(i,npts-j)
            sym(i,middle-j)=conj(unitv(j))*kmat(i,j)
            endfor
        endfor
    kmat=sym
    new=transpose(kmat)
    sign=float(new)/abs(float(new))
    newer=sign*abs(float(new))
    tv,rebin(bytscl(newer,min=-25,max=25,top=254),mfact*npts,$
    nfact*(2*nharms-1))

    xyouts,0.05,0.05,'freq='+strtrim(string((f+1)/2.),2),$
    /normal,color=254

    print,'Frequency bin = ',f
    wait,0.5
    char=get_kbrd(0)
    if char ne '' then begin
        print,'Hit any key to continue'
        hak
        endif

    endfor
end
```

```
; window.pro
; Last modification: 9 Jun 92

;-----------------------------------------------------------------
; This program takes model data in the frequency domain and performs
; the windowing prescribed by NRL, then presents a comparison of the
; model results with the experimental data in the frequency domain
;-----------------------------------------------------------------

common header,jobname,comment,$
nka,npatts,nthetainc,nareas,ncoords,nharms,nobs,isymm,$
kastart,kainc,thetaincstart,thetaincinc,phiincstart,phiincinc,$
thetaobsstart,thetaobsinc,rhof,cf,rhom,young,nu,eta

; Select the data set

; Change pathname data file names as required
pid=' '
print,'input pid, eg 4a 4b'
read,pid
pathname='/data/schenck/dset2/'
;pathname=' '
;print,'input pathname'
;read,pathname
jobname='      '
print,'Input jobname (no extension) '
read,jobname
print,'Input incidence angle in degrees'
read,iinc
case pid of
    '4a':begin
        refname='bm4aref.daw' ;reference time series
        case iinc of
            0:begin
                extension='.fw0'   ; computational data
                cdat='cleana0.dat' ; cleaning window data
                shifty=-0 ; to account for orientation of target
                ; in NRL tank
                fname='bm4a0.daw'  ; experimental echo time series
                end

            45:begin
                extension='.fw4'
                cdat='cleana4.dat'
                shifty=-15
                fname='bm4a45.daw'
                end

            90:begin
                extension='.fw9'
                cdat='cleana9.dat'
                shifty=-30
                fname='bm4a90.daw'
                end
            endcase
        end
    '4b':begin
        refname='bm4bref.daw'
        case iinc of
            0:begin
                extension='.fw0'
                cdat='cleanb0.dat'
                shifty=-0
                fname='bm4b0.daw'
                end

            45:begin
                extension='.fw4'
                cdat='cleanb4.dat'
                shifty=-15
                fname='bm4b45.daw'
                end

            90:begin
                extension='.fw9'
                cdat='cleanb9.dat'
                shifty=-30
                fname='bm4b90.daw'
                end
            endcase
        end
    else:print,'Incorrect jobname'
    endcase

fullname=pathname+jobname

; Read the header and open the file
rdhdr,filename=fullname
fullname=fullname+extension
get_lun,iunit
openr,iunit,fullname
aa=assoc(iunit,complexarr(nka,nharms,nobs,isymm))
data=aa(0)
free_lun,iunit
print,'Finished reading model data set'

; this next part could be made simpler,
; since we only want phicut=0

deltaphi=180
numphi=1+fix(360./deltaphi)
angles=deltaphi*(!pi/180.)*findgen(numphi)
ivect=indgen(nharms)
cosangle=transpose(cos(ivect#angles))
sinangle=transpose(sin(ivect#angles))
npff=complexarr(numphi,nobs,nka)
for kabin=0,nka-1 do begin
    ctemp=complexarr(numphi,nobs)
    if isymm eq 1 then ctemp=cosangle#reform(data(kabin,*,*,0))
    if isymm eq 2 then ctemp=cosangle#reform(data(kabin,*,*,0)) $
    +sinangle#reform(data(kabin,*,*,1))
    npff(*,*,kabin)=ctemp
    endfor

; Calculate the full 360 degree pattern of computed target $
; strength

xsz=2*nobs-1
ysz=nka
halfway=(numphi-1)/2
var=complexarr(xsz,ysz)
var(0:nobs-1,*)=npff(0,*,*)  ; phicut = 0
var(nobs:xsz-1,*)=reverse(reform(npff(halfway,1:nobs-1,*)),1)
print,'Full azimuthal pattern constructed'

window,5,xsize=900,ysize=400,xpos=200,title=$
'5.Target strength vs angle and frequency'
loadct,5
bytc=bytscl(20*alog10(abs(var)),min=-30,max=30,$
top=!d.n_colors-1)
tv,rebin(bytc,2*121,331),600,35
xyouts,0.72,0.95,'Unwindowed model',/normal

add=42 ; adjust lowest non-zero bin of computed data
; (firstbin*binwidth=1.7kHz)

; First, we'll work with the reference signal

; Read in the reference (incident) time series

refname='/data/schenck/expt4/'+refname
get_lun,iunit
openr,iunit,refname,/f77_unformatted
bb=assoc(iunit,fltarr(4096))
ref=bb(0)               ;reference (incident) time series
free_lun,iunit
tape_info=ref(4080:4095)
print,tape_info
ref(4080:4095)=0.       ; replace last 16 bins with zero

ref=shift(ref,380)
window,1,xsize=400,ysize=200,xpos=150,ypos=700,$
title='1.Reference signal'
plot,ref(0:2500),yrange=[-25,25],ystyle=1 ; plot the time series
tlength=12423 ; to achieve 2 usec sample period
; in the computed time series
rpad=replicate(0.0,tlength)
rpad(0:4095)=ref
cpad=fft(rpad,-1)
magpinc=avg(abs(cpad(add:add+nka-1)))

;;; change pathnames if required
```

```
fullname='/data/schenck/expt4/'+fname
get_lun,iunit
openr,iunit,fullname,/f77_unformatted
aa=assoc(iunit,fltarr(121,4096))
echo=aa(0)
free_lun,iunit
print,'Finished reading the experimental data'

; The correction factor accounts for the source,
; target, receiver geometry
geocorrect=2*2*sqrt(2.18)/(2.239*2.18*0.0254*sqrt(1.96))
ech=geocorrect*echo

window,2,xsize=400,ysize=200,xpos=150,ypos=470,$
title='2.Experimental echo'
loadct,5
window,3,xsize=400,ysize=200,xpos=150,ypos=10,$
title='3.Computed time series'
window,4,xsize=400,ysize=200,xpos=150,ypos=240,$
title='4.Windowed time series'

ffsurf=complexarr(121,331)
modspec=complexarr(121,331)

; Now develop cosine squared window for each observation angle
; this information comes from Brian Houston's memo re from
; 3600 to 3700 data

cdat='~/prob4/'+cdat
get_lun,kunit
openr,kunit,cdat
cleanarr=intarr(4,121)
readf,kunit,cleanarr
free_lun,kunit

print,cleanarr

; Now we'll start the large loop over observation angle

for j=0,120 do begin

    k=-(j+shifty)
    if k lt 0 then k=k+121

    ; Next, let's process the experimental echo

    print,echo(k,4094)       ; print angles of observation
    ech(k,4080:4095)=0.      ; zero the last sixteen bins

    longecho=replicate(0.,tlength)
    longecho(0:4095)=reform(ech(k,*))
    backspec=fft(longecho,-1) ; convert to frequency domain
    ffsurf(j,*)=backspec(add:add+nka-1)

```

```
wset,2
plot,ech(k,0:2500),yrange=[-10.,10.],ystyle=1

; Generate and overplot the cleaning window

frontstart=cleanarr(0,k)
frontend=cleanarr(1,k)
backstart=cleanarr(2,k)
backend=cleanarr(3,k)
flength=frontend-frontstart+1
blength=backend-backstart+1
piover2=!pi/2.
frontw=(sin(piover2*findgen(flength)/float(flength-1)))^2
backw=(cos(piover2*findgen(blength)/float(blength-1)))^2
cleanw=replicate(0.0,4096)
cleanw(frontstart:frontend)=frontw
cleanw(frontend+1:backstart-1)=1.0
cleanw(backstart:backend)=backw

longclean=replicate(0.,tlength)
longclean(0:4095)=cleanw
oplot,5.*longclean(0:2500),color=120
wait,0.02

; Next, we will process the computed results

bsff=reform(var(j,*))*cpad(add:add+nka-1) ; positive freqs
part=replicate(0.0,tlength)
padded=complex(part,part)    ; a complex array of zeroes
padded(0+add:add+nka-1)=bsff ; fill in the negative frequencies
rev=conj(reverse(bsff))      ; ensures a real time series

; fill in the negative freqs
padded(tlength-nka+1-add:tlength-add)=rev(0:nka-1)  ;
tseries=fft(padded,1)        ; take the FFT
modt0=float(tseries)

wset,3
plot,modt0,yrange=[-10.0,10.0],ystyle=1
oplot,imaginary(tseries),color=120 ; this should be zero
wait,0.02

; Next, apply the cleaning window to the computed results

newc=longclean*modt0 ; apply the window in time domain
newspec=fft(newc,-1) ; compute the windowed model spectrum
modspec(j,*)=newspec(add:add+nka-1)

wset,4
plot,newc(0:2500),yrange=[-10.0,10.0],ystyle=1
oplot,5.*longclean(0:2500),color=120
wait,0.02

print,'j=',strtrim(string(j),2),'     k=',strtrim(string(k),2)
```

```
    endfor


;nrlimg=reverse(shift(20*alog10(abs(ffsurf)/magpinc),
;shifty,0)); the exptl data
nrlimg=20*alog10(abs(ffsurf)/magpinc)   ; the exptl data

; the shift and reverse are needed to make my NRL's
;angles the same as for Benchmark problems

bytx=bytscl(nrlimg,min=-30,max=30,top=!d.n_colors-1)

wset,5
tv,rebin(bytx,2*121,331),300,35
xyouts,0.4,0.95,'Experimental data',/normal

bytw=bytscl(20*alog10(abs(modspec)/magpinc),min=-30,$
max=30,top=!d.n_colors-1)

wset,5
loadct,5
tv,rebin(bytw,2*121,331),20,35
xyouts,0.08,0.95,'Windowed model',/normal

phasec=atan(imaginary(var),float(var))
phasex=atan(imaginary(ffsurf),float(ffsurf))
phasew=atan(imaginary(modspec),float(modspec))
window,/free
tvscl,phasew,50,50
tvscl,phasex,200,50
tvscl,phasec,350,50


goto,jump
hardcopy,filename=strtrim(jobname,2)+$
strtrim(string(fix(iinc)),2)+'.eps',xsize=1.21,ysize=3.31
tv,bytc
closeit
hardcopy,filename='win'+strmid(jobname,1,2)+$
strtrim(string(fix(iinc)),2)+'.eps',xsize=1.21,ysize=3.3
tv,rebin(bytw,121,330)
closeit
hardcopy,filename='ex'+strmid(jobname,1,2)+$
strtrim(string(fix(iinc)),2)+'.eps',xsize=1.21,ysize=3.3
tv,rebin(bytex,121,330)
closeit
jump:

end
```

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As part of the Submarine Technology Program, the Defense Advanced Research Projects Agency (DARPA) recently sponsored a Low-Frequency Structural Acoustics Benchmark Exercise. The purpose of the exercise was to test and validate several major computational codes that have been developed to solve acoustic scattering problems of elastic objects in a fluid. This report describes some of the visualization techniques and procedures that were developed to review, compare, and analyze the large amount of computational data generated in the exercise.

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